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#### SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Yohei Nakanishi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Seiji Tanuma, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan and Takatoshi Mayama, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan have invented certain new and useful improvements in

#### IN-PLANE SWITCHING LIQUID CRYSTAL DISPLAY DEVICE

of which the following is a specification : -

1     TITLE OF THE INVENTION

          IN-PLANE SWITCHING LIQUID CRYSTAL DISPLAY  
DEVICE

5     BACKGROUND OF THE INVENTION

          The present invention generally relates to  
liquid crystal display devices and more particularly  
to an in-plane switching liquid crystal display  
device. An in-plane switching liquid crystal display  
10 device is a device driven by an electric field acting  
parallel to the liquid crystal layer forming the  
liquid crystal display device.

          Conventionally, driving of a liquid crystal  
display device has been achieved by applying an  
15 electric field to a liquid crystal layer confined by a  
pair of substrates such that the electric field acts  
perpendicularly to the liquid crystal layer. On the  
other hand, there is a proposal of a so-called in-  
plane switching (IPS) liquid crystal display device,  
20 in which an electric field is applied to the liquid  
crystal layer such that the electric field acts in the  
direction parallel to the substrates. In such an IPS  
liquid crystal display device, an interdigital  
electrode is provided on one of the foregoing  
25 substrates.

          FIGS.1A and 1B show the principle of such an  
IPS liquid crystal display device.

          Referring to FIG.1A, a liquid crystal layer  
13 containing therein liquid crystal molecules is  
30 confined between a pair of mutually opposing glass  
substrates 11 and 12 in such a manner that the liquid  
crystal layer makes an intimate contact with a  
molecular alignment film 11A covering the substrate 11  
and also an intimate contact with a molecular  
35 alignment film 12A covering the substrate 12.  
Further, polarizers 11B and 12B are disposed at  
respective outer sides of the glass substrates 11A and

1 11B in a crossed Nicol state. Further, a pair of  
electrodes 14A and 14B are provided on the glass  
substrate 11 in a state that the electrodes 14A and  
14B are covered by the molecular alignment film 11A.

5 In the non-activated state of FIG.1A, there  
is no driving voltage applied across the electrodes  
14A and 14B and the liquid crystal molecules 13A of  
the liquid crystal layer 13 are aligned in a  
predetermined direction in a plane generally parallel  
10 to the substrates 11 and 12.

In the activated state of FIG.1B, on the  
other hand, a driving voltage is applied across the  
electrodes 14A and 14B, and an electric field is  
induced in the liquid crystal layer 13 in the  
15 direction generally parallel to the liquid crystal  
layer 13. As a result of the electric field, the  
direction of the liquid crystal molecules 13A, or  
molecular orientation, is changed. An IPS liquid  
crystal display device achieves the desired optical  
20 switching by using such a change of the molecular  
orientation of the liquid crystal molecules 13A. Due  
to the fact that the change of the molecular  
orientation occurs in the plane parallel to the liquid  
crystal layer 13, an IPS liquid crystal display device  
25 generally provides a superior viewing angle as  
compared with the conventional twist-nematic (TN)  
liquid crystal display devices.

On the other hand, such an IPS liquid  
crystal display device, lacking an electrode on the  
30 opposing substrate 12 contrary to a conventional TN  
liquid crystal display device, tends to induce  
polarization in the molecular alignment film 12A,  
while such a polarization induced in the molecular  
alignment film 12A tends to cause the problem of image  
35 sticking or afterimage, in which the represented image  
tends to remain after the image has been changed.  
This problem of image sticking becomes particularly

1 acute when the liquid crystal display device is used  
to display an image for a prolonged time period.

In order to eliminate the problem of image  
sticking, it is necessary to use a low-resistance  
5 liquid crystal having a resistance lower than the  
resistance of the liquid crystal used in a  
conventional TN liquid crystal display device, for the  
liquid crystal layer 13. However, such a liquid  
crystal having a low resistance generally has a large  
10 dielectric constant and tends to dissolve impurities.  
In other words, a low-resistance liquid crystal is  
vulnerable to contamination. Such a contamination may  
come from the sealing material of the liquid crystal  
display device or from the molecular alignment film.  
15 Once the liquid crystal is contaminated, the  
representation performance of the liquid crystal  
display device is severely deteriorated.

Further, it should be noted that the  
electric field 13B induced in the liquid crystal layer  
20 13 in the driving state of the liquid crystal display  
device is not exactly parallel to the plane of the  
liquid crystal layer 13 in the vicinity of the  
electrode 14A or 14B. This means that the electric  
field component parallel to the plane of the liquid  
25 crystal layer 13 becomes small and the response speed  
of the liquid crystal molecules 13A becomes  
accordingly small in the vicinity of the electrodes  
14A and 14B.

Thus, there is an acute demand of improved  
30 performance for the conventional IPS liquid display  
device.

#### SUMMARY OF THE INVENTION

Accordingly, it is a general object of the  
35 present invention to provide a liquid crystal display  
device wherein the foregoing problems are eliminated.

The present invention provides a liquid

1 crystal display device, comprising:  
first and second, mutually opposing  
substrates;  
a liquid crystal layer confined between said  
5 first and second substrates;  
an electrode formed on said first substrate  
so as to create an electric field acting generally  
parallel to a plane of said liquid crystal layer; and  
a plurality of pixels being defined in said  
10 liquid crystal layer,  
each of said plurality of pixels including  
therein a plurality of domains having respective  
orientations for liquid crystal molecules, such that  
said orientation is different between a domain and  
15 another domain within said plane of said liquid  
crystal layer.

According to the present invention, it is  
possible to improve the response speed of the IPS  
liquid crystal display device, by providing domains in  
20 each of the pixels in the liquid crystal layer such  
that the molecular orientation is different between a  
domain and another domain when compared in the plane  
of the liquid crystal layer. More specifically, the  
present invention achieves the desired improvement of  
25 response by twisting the liquid crystal molecules, in  
the non-activated state of the liquid crystal display  
device, such that the molecular orientation of the  
liquid crystal molecules in the domain adjacent to the  
electrode is closer to the molecular orientation in  
30 the activated state of the liquid crystal display  
device, as compared with the molecular orientation of  
the liquid crystal molecules in the domain far from  
the electrode. As a result, the liquid crystal  
molecules adjacent to the electrode are aligned in the  
35 activated direction immediately upon application of  
the driving voltage to the electrode, in spite of the  
fact that the electric field component included in the

1 plane of the liquid crystal layer is small in the  
vicinity of the electrode.

Other objects and further features of the  
present invention will become apparent from the  
5 following detailed description when read in  
conjunction with the attached drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIGS.1A and 1B are diagrams showing the  
10 principle of a conventional IPS liquid crystal display  
device;

FIGS.2A and 2B are diagrams showing the  
construction of an IPS liquid crystal display device  
according to first and second embodiments of the  
15 present invention;

FIGS.3A and 3B are diagrams showing the  
construction of an IPS liquid crystal display device  
of the first embodiment;

FIGS.4A and 4B are diagrams showing a  
20 modification of the IPS liquid crystal display device  
of the first embodiment;

FIG.5 is a diagram showing the construction  
of an IPS liquid crystal display device according to a  
third embodiment of the present invention;

25 FIG.6 is a diagram showing the electro-optic  
property of a conventional IPS liquid crystal display  
device;

FIGS.7A and 7B are diagrams showing the  
principle of an IPS liquid crystal display device  
30 according to a fourth embodiment of the present  
invention;

FIGS.8A and 8B are diagrams showing examples  
of the electrodes used in the IPS liquid crystal  
display device of the fourth embodiment;

35 FIGS.9A and 9B are diagrams further examples  
of the electrodes used in the IPS liquid crystal  
display device of the fourth embodiment;

1           FIGS.10A and 10B are diagrams showing the  
viewing angle of the IPS liquid crystal display device  
of the fourth embodiment in comparison with the  
viewing angle of a conventional IPS liquid crystal  
5   display device;

FIG.11 is a diagram showing another  
construction of the IPS liquid crystal display device  
of the fourth embodiment of the present invention;

FIG.12 is a diagram showing further  
10   construction of the IPS liquid crystal display device  
of the fourth embodiment; and

FIG.13 is a diagram showing still further  
construction of the IPS liquid crystal display device  
of the fourth embodiment.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT  
[FIRST EMBODIMENT]

FIGS.2A and 2B show the construction of an  
IPS liquid crystal display device 20 according to a  
20   first embodiment of the present invention.

Referring to FIG.2A, the liquid crystal  
display device 20 includes a pair of mutually opposing  
glass substrates 21 and 22, and a liquid crystal layer  
23 is confined in a space formed between the glass  
25   substrates 21 and 22. Further, the glass substrate 21  
carries thereon a TFT (thin-film transistor) having a  
gate electrode 24A, a pixel electrode 24B and a source  
electrode 24C.

As represented in FIG.2A, the gate electrode  
30   24A is covered by an insulation film 21A provided on  
the glass substrate 21 and constituting the gate  
insulation film of the TFT, wherein the foregoing  
pixel electrode 24B and the source electrode 24C are  
both formed on the insulation film 21A. Further, the  
35   glass substrate 21 carries thereon an opposing  
electrode 24D with a separation from the pixel  
electrode 24B in the state that the opposing electrode

1 24D is covered by the insulation film 21A.

It should be noted that the foregoing TFT is covered by a molecular alignment film 21B provided on the insulation film 21A, and the liquid crystal layer  
5 23 is formed in an intimate contact with the molecular alignment film 21B. In the foregoing construction, a pixel region is defined between the pixel electrode 24B and the opposing electrode 24D.

On the opposing substrate 22, on the other  
10 hand, there is provided an opaque mask pattern 22A in correspondence to the TFT on the substrate 21, and a color filter 22C is formed on the substrate 22 adjacent to the opaque mask pattern 22A, such that the color filter 22C is located in correspondence to the  
15 pixel region defined in the substrate 21 between the electrode 24B and the electrode 24D. The color filter 22C thus formed is covered by a molecular alignment film 22B, wherein the molecular alignment film 22B is provided such that the molecular alignment film 22B  
20 makes an intimate contact with the liquid crystal layer 23 in the state that the molecular alignment film 22B faces the molecular alignment film 21B formed on the glass substrate 21.

Further, the liquid crystal display device  
25 20 includes a polarizer 25 on the lower surface of the glass substrate 21 and an analyzer 26 on the top surface of the glass substrate 22 in a crossed Nicol state in which the optical absorption axes of the polarizer 25 and the analyzer 26 intersect  
30 perpendicularly.

FIG.2B shows the electrode pattern of the liquid crystal display device 20 in a plan view.

Referring to FIG.2B, each of the TFTs is formed at an intersection of a gate bus line which  
35 corresponds to the gate electrode 24A and a source bus line which corresponds to the source electrode 24C, and the pixel electrode 24B and the opposing electrode



1     24D extend parallel with each other in the elongating  
direction of the source bus line.

         In the liquid crystal display device 20  
having such a construction, an electric field acting  
5     generally parallel to the plane of the liquid crystal  
layer 23 is induced between the pixel electrode 24B  
and the opposing electrode 24D in response to the  
turning-ON of the TFT, and the electric field thus  
induced causes a change in the orientation of the  
10    liquid crystal molecules 23A constituting the liquid  
crystal layer 23 in the plane of the liquid crystal  
layer 23. In response to such a change in the  
orientation of the liquid crystal molecules, the  
optical beam passing through the liquid crystal  
15    display device 20 is turned on and off.

         FIG.3A shows the liquid crystal display  
device 20 in a cross-section taken along a line A-A'  
of FIG.2B, while FIG.3B shows a plan view  
corresponding to FIG.3A.

20     Referring to FIGS.3A and 3B, there are  
formed pixel regions  $23_1$  and  $23_2$  between the pixel  
electrode 24B and the opposing electrodes 24D formed  
adjacent to the pixel electrode 24B at respective  
opposite sides thereof, wherein each of the pixel  
25    regions  $23_1$  and  $23_2$  includes a pair of sub-regions or  
domains  $\theta_2$ , one adjacent to the electrode 24B and the  
other adjacent to the electrode 24D, and another sub-  
region or domain  $\theta_1$  is formed in the same pixel region  
 $23_1$  or  $23_2$  between a pair of the sub-regions  $\theta_2$  thus  
30    formed. Thus, each of the pixel region  $23_1$  or  $23_2$  of  
the present embodiment has a domain structure formed  
of the sub-regions  $\theta_1$  and  $\theta_2$ .

         As represented in FIG.3B, the liquid crystal  
molecules 23A, more specifically the elongating  
35    direction of the liquid crystal molecules 23A, forms  
an angle  $\theta_1$  of typically about  $15^\circ$  in the non-  
activated state of the liquid crystal display device.

1 with respect to the elongating direction of the pixel  
electrode 24B, and thus the elongating direction of  
the source bus line 24C, in the sub-region  $\theta_1$ . On the  
other hand, in the sub-region  $\theta_2$ , the liquid crystal  
5 molecules 23A forms an angle  $\theta_2$  of typically about  $30^\circ$   
with respect to the elongating direction of the source  
bus line 24C in the non-activated state of the liquid  
crystal display device.

Thus, it can be seen that the liquid crystal  
10 molecules 23A form, in the non-activated state of the  
liquid crystal display device 20, an angle of about  
 $75^\circ$  with respect to the direction of the electric  
field E formed between the electrode 24B and the  
electrode 24D in the sub-region  $\theta_1$ , while the angle of  
15 the liquid crystal molecules 23A with respect to the  
electric field E becomes about  $60^\circ$  in the sub-region  
 $\theta_2$ .

By setting the direction of the liquid  
crystal molecules 23A for the non-activated state of  
20 the liquid crystal display device 20 to be closer to  
the activated direction of the liquid crystal  
molecules 23A, which is realized in the activated  
state of the liquid crystal display device 20, it  
becomes possible to align the liquid crystal molecules  
25 quickly in the desired activated direction  
corresponding to the activated state of the liquid  
crystal display device 20 upon the activation of the  
liquid crystal display device 20. In other words, the  
liquid crystal display device 20 of the present  
30 embodiment shows an improved response speed.

In fact, it was confirmed, in an IPS liquid  
crystal display device having a resolution of  $640 \times$   
 $480$  pixels and constructed according to FIGS. 3A and  
3B, in that the sum of the turn-on response time  $t_{on}$   
35 and the turn-off response time  $t_{off}$  is reduced to 50  
ms. It should be noted that this value is a  
substantial improvement over the conventional value of

1 60 ms. In this experiment conducted by the inventor,  
a liquid crystal mixture exclusively formed of a  
fluoric liquid crystal component and a neutral liquid  
5 molecular alignment film supplied from Japan Synthetic  
Rubber, K.K. under the trade name of AL1054. The  
foregoing liquid crystal mixture used in the  
experiment has a dielectric anisotropy  $\Delta\epsilon$  of 8.0 and  
the initial resistivity of about  $1 \times 10^{14} \Omega\text{cm}$ .  
10 Further, the sub-regions or domains  $\theta_1$  and  $\theta_2$  of  
FIGS.3A and 3B are formed by a rubbing process  
conducted under existence of a mask.

In the construction of FIGS.3A and 3B that  
includes the sub-regions  $\theta_1$  and  $\theta_2$ , in which the  
15 direction of alignment of the liquid crystal molecules  
is changed between the sub-regions  $\theta_1$  and  $\theta_2$ , it is  
inevitable that leakage of light occurs to some  
extent. In view of this, it is preferable to set the  
width of the sub-region  $\theta_2$  to be less than about  $1 \mu\text{m}$ .  
20 In this case, the width of the sub-region  $\theta_1$  becomes  $4 \mu\text{m}$   
as represented in FIG.3B, assuming that the pixel  
region  $23_1$  or  $23_2$  has a width of  $6 \mu\text{m}$ . Further, the  
sub-region  $\theta_2$  may be covered by the opaque mask 22A  
provided on the opposing substrate 26 for cutting the  
25 leakage of the light caused in the sub-region  $\theta_1$ . In  
this case, the sub-region  $\theta_1$  becomes the effective  
pixel region. Smaller the sub-region  $\theta_2$ , larger than  
the effective pixel region  $\theta_1$ .

In the construction of FIGS.3A and 3B, the  
30 direction of alignment of the liquid crystal molecules  
are set generally symmetric about the pixel electrode  
 $24B$  in the pixel region  $23_1$  and the pixel region  $23_2$   
that are disposed adjacent to the pixel electrode  $24B$ .  
By setting the direction of the liquid crystal  
35 molecules as such, the viewing-angle characteristic of  
the liquid crystal display device 20 is improved  
further.

1           It is of course possible to align the liquid  
crystal molecules in the same direction in the pixel  
region  $23_1$  and in the pixel region  $23_2$  as represented  
in FIGS.4A and 4B. In the construction of FIGS.4A and  
5       4B, the domain structure of the pixel region  $23_1$  is  
repeated in the pixel region  $23_2$ . As other features  
of FIGS.4A and 4B are identical with those of FIGS.3A  
and 3B, further description thereof will be omitted.

10       [SECOND EMBODIMENT]

          Meanwhile, it is important to use a liquid  
crystal having a large initial resistivity for the  
liquid crystal layer 23 in order to secure a reliable  
and stable operation of a liquid crystal display  
15       device. On the other hand, the use of such a liquid  
crystal of large initial resistivity in an IPS liquid  
crystal display device tends to cause the problem of  
sticking of images or afterimage as mentioned  
previously.

20       In order to overcome the foregoing problem,  
the present embodiment reduces the resistance of the  
liquid crystal, which has a large initial resistivity,  
by exposing the molecular alignment films 21B and 22B  
with a ultraviolet radiation at the time of  
25       fabrication of the liquid crystal display device.  
Thereby, by using a polarized ultraviolet beam for  
this purpose, it is possible to set the direction of  
alignment of the liquid crystal molecules, which is  
caused by the molecular alignment films 21B and 22B,  
30       such that the liquid crystal molecules are aligned  
coincident to the plane of polarization of the  
polarized ultraviolet beam.

          TABLE I below shows the result of  
experiments with regard to the sticking of images  
35       conducted on the IPS liquid crystal display device 20  
of FIGS.2A and 2B for the case in which a polarized  
ultraviolet beam is applied to the molecular alignment

1 films 21B and 22B.

TABLE I

5		EXP-1	EXP-2	EXP-3	COMP
	INITIAL	GOOD	GOOD	GOOD	GOOD
	AFTER 12H	GOOD	GOOD	GOOD	BAD
	AFTER 24H	FAIR	GOOD	GOOD	BAD
10	RUNNING	GOOD	GOOD	GOOD	GOOD

Referring to TABLE I, the Experiment-1 (EXP-1) is conducted by using the AL1054 molecular alignment film of Japan Synthetic Rubber, K.K. for the molecular alignment films 21B and 22B and irradiating thereto a polarized ultraviolet beam uniformly with a dose of about  $6 \text{ J/cm}^2$ . The glass substrates carrying the molecular alignment films 21B and 22B thus processed, are used to assemble a liquid crystal panel, and the liquid crystal display device 20 is formed by introducing a liquid crystal mixture of a high-resistivity liquid crystal into the liquid crystal panel as the liquid crystal layer 13. The liquid crystal mixture used in the Experiment-1 contains exclusively a fluoric liquid crystal component and a neutral liquid crystal component and is characterized by a dielectric anisotropy  $\Delta\epsilon$  of 8.0 and the initial resistivity of about  $1 \times 10^{14} \Omega\text{cm}$ . In the liquid crystal display device 20 used in this experiment, there is no domain structure formed, contrary to the embodiment of FIGS.3A and 3B or FIGS.4A and 4B.

For the sake of comparison, a liquid crystal display device is formed with the same structure as the liquid crystal display device 20 of FIGS.2A and 2B, except that the ultraviolet radiation is omitted.

1 In this Comparative Experiment, the molecular  
alignment films 21B and 22B are subjected to a rubbing  
process.

5 In the experiment of TABLE I, the degree of  
image sticking was evaluated visually after displaying  
a stationary pattern image at 50°C continuously for 12  
hours and 24 hours. Further, a running test was  
conducted in which the existence of non-uniformity in  
image representation was examined after continuous  
10 running operation for 500 hours at 50°C.

Referring to TABLE I, it can be seen that a  
distinct sticking of images was observed in the  
Comparative Experiment after 12 hours or 24 hours of  
operation. On the other hand, in the case of the  
15 Experiment-1, no image sticking was observed at all  
after 12 hours. Further, no image sticking was  
observed after 24 hours, as long as the liquid crystal  
display device is viewed from the front direction.  
When viewed from an oblique direction, on the other  
20 hand, appearance of a minor image sticking was  
observed in the experiment-1 when the liquid crystal  
display device is viewed from an oblique direction.

In the Experiment-2 (EXP-2), on the other  
hand, the sub-region  $\theta_1$  of FIGS.3A and 3B was exposed  
25 to the polarized ultraviolet beam with a dose of about  
 $6 \text{ J/cm}^2$  while the sub-region  $\theta_2$  was exposed to the  
same polarized ultraviolet beam with a dose of about  
 $12 \text{ J/cm}^2$ . In this experiment, the polarization plane  
was not changed between the case of exposing the sub-  
30 region  $\theta_1$  and the case of exposing the sub-region  $\theta_2$ .  
Thus, the direction of liquid crystal molecular  
alignment is the same between the sub-region  $\theta_1$  and  
the sub-region  $\theta_2$  in the Experiment-2.

As will be noted from TABLE I, the problem  
35 of image sticking was eliminated in any of the initial  
state, after 12 hours, and after 24 hours. Further,  
no image sticking or non-uniformity was observed in

1 the running test.

In the Experiment-3 (EXP-3), a process similar to the process of the Experiment-2 is conducted, except that a mask process is used in the step of exposing the sub-region  $\theta_2$  with the polarized ultraviolet beam, wherein the polarization plane of the polarized ultraviolet beam is changed when exposing the sub-region  $\theta_2$  with respect to the case of exposing the sub-region  $\theta_1$ . Thus, a domain structure similar to the one shown in FIGS.3A and 3B or 4A and 4B is formed in the liquid crystal layer 23 in the Experiment-3. In the Experiment-3, too, the exposure dose of the sub-region  $\theta_2$  is set to  $12\text{J}/\text{cm}^2$ , which is twice as large as the exposure dose used for the sub-region  $\theta_1$ .

As can be seen from TABLE I, the problem of image sticking is totally eliminated in any of the initial state, after 12 hours, after 24 hours, and the running test for 500 hours. It should be noted that the liquid crystal display device used in the Experiment-3 provides an improved response speed due to the domain structure represented in FIGS.3A and 3B or FIGS.4A and 4B.

#### 25 [THIRD EMBODIMENT]

FIG.5 shows the construction of a liquid crystal display device 30 according to a third embodiment of the present invention, wherein those parts corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to FIG.5, the liquid crystal display device 30 uses a high-resistivity liquid crystal mixture containing therein exclusively a fluoric liquid crystal component and a neutral liquid crystal component for the liquid crystal layer 23, wherein the resistance of the liquid crystal layer 23

1 is reduced by introducing thereinto an impurity material.

5 In the example of FIG.5, an epoxy resin is provided on the surface of the spacers 31 that are distributed uniformly in the liquid crystal layer 23 so that an impurity material is released from the epoxy resin into the liquid crystal layer 23. In the case such spacers are introduced into 100g of the liquid crystal mixture having a resistivity of about 1  
10  $\times 10^{14} \Omega \text{cm}$  with an amount of 0.003g and held at 100°C for 60 minutes, the resistivity of the liquid crystal layer 13 is reduced to about  $1 \times 10^{12} \Omega \text{cm}$ .

Thus, in the present embodiment, an SVGA-TFT liquid crystal panel of the 11.3-inch size was  
15 fabricated based on the liquid crystal display device 30 of FIG.5 and the sticking of images was examined for the liquid crystal display panel thus fabricated. According to the test conducted by the inventor, it was confirmed that a result similar to the Experiment-  
20 1 or Experiment-2 of TABLE I is obtained even in such a case the molecular alignment films 21B and 22B are processed by a rubbing process.

It should be noted that the desired decrease of the resistivity of the liquid crystal layer 23 is  
25 not limited to the introduction of impurity component released from the surface of the spacer 31 shown in FIG.5, but may be achieved also by admixing a liquid crystal of low initial resistance such as the liquid crystal containing a CN component to the liquid  
30 crystal mixture of the liquid crystal layer 23. As a result of decrease of the resistivity in the liquid crystal layer 23, the problem of image sticking of the liquid crystal display device is effectively eliminated.

35 In the present invention, it should be noted that the liquid crystal mixture used for the liquid crystal layer 23 per se has a large resistance. Thus,



1 the deterioration of the liquid crystal layer 23  
caused by the dissolution of the seal is suppressed  
and the liquid crystal display device shows an  
improved, long-term reliability.

5

[FOURTH EMBODIMENT]

FIG.6 shows the electro-optic  
characteristic, more specifically the relationship  
between the driving voltage  $V$  and the transmittance  $T$   
10 of a typical conventional IPS liquid crystal display  
device. In FIG.6, the broken line shows the  
transmittance  $T$  as viewed from the front direction of  
the liquid crystal display device, while the  
continuous line shows the transmittance  $T$  as viewed  
15 from an oblique direction in which the azimuth angle  
is  $135^\circ$  and the polar angle is  $60^\circ$ .

Referring to FIG.6, it can be seen that  
there appears a reversal in the relationship between  
the transmittance  $T$  and the driving voltage  $V$ , in the  
20 region where the driving voltage  $V$  is less than about  
3 V, in that the transmittance  $T$  decreases with  
increasing driving voltage  $V$ .

FIG.7A shows the relationship between the  
transmittance  $T$  and the driving voltage  $V$  of an IPS  
25 liquid crystal display device having an interdigital  
electrode of FIG.7B, wherein FIG.7A shows the  
relationship in an enlarged scale in the voltage range  
lower than 3V. It should be noted that the  
interdigital electrode of FIG.7B includes the pixel  
30 electrode 24B and the opposing electrode 24D of FIG.2B  
in the state that each of the electrodes 24B and 24D  
has a plurality of electrode fingers extending  
parallel with each other.

Referring to FIG.7A, it can be seen that,  
35 while the driving voltage  $V$  corresponding to the  
maximum inversion of the transmittance  $T$  changes  
between the case in which the interval between the

1 electrode fingers is set to  $6\text{ }\mu\text{m}$  and the case in which  
the interval is set to  $15\text{ }\mu\text{m}$ , the average  
transmittance of these two cases shows a reduced  
magnitude of inversion as a result of the  
5 superposition of the two characteristic curves.

Thus, in the present embodiment, a plurality  
of regions of mutually different electro-optic  
characteristics are formed in each of the pixels of  
the IPS liquid crystal display 20 of FIG.2A, so that  
10 the electro-optic characteristics are averaged in each  
pixel. As a result of the superposition of the  
electro-optic characteristics, the relationship  
between the transmittance  $T$  and the driving voltage  $V$   
is averaged, and the problem of inversion of contrast,  
15 which tends to occur when the liquid crystal display  
device is viewed from an oblique direction, is  
minimized.

FIG.8A shows the construction of an  
interdigital electrode used in the present embodiment  
20 for forming the regions of different electro-optic  
characteristics in a pixel.

Referring to FIG.8A, the interdigital  
electrode has a construction generally similar to the  
interdigital electrode of FIG.7B, except that the  
25 pixel electrode 24B and the opposing electrode 24D are  
displaced laterally to each other. As a result of  
such a laterally displaced construction of the  
electrodes 24B and 24D, there are formed a first  
electrode interval  $W_1$  and a second electrode interval  
30  $W_2$  larger than the first electrode interval  $W_1$  in the  
interdigital electrode. Thus, by using the  
interdigital electrode of FIG.8A, it becomes possible  
to form the regions of different electro-optic  
properties in each pixel of the liquid crystal layer  
35 23. Thereby, the liquid crystal display device of the  
present embodiment provides an improved viewing angle  
characteristic in which the inversion of contrast is

1 minimized.

It will be noted that a similar result of improved viewing angle characteristic is achieved also by using the interdigital electrode of FIG.8B.

5 FIG.9A shows an example of the interdigital electrode for use in an IPS liquid crystal display device, in which it will be noted that the electrode fingers 24b of the pixel electrode 24B are formed to have a tapered shape. Further, FIG.9B shows another  
10 example in which the electrode fingers 24b of the pixel electrode 24B are formed to have a sawtooth pattern. In the example of FIG.9B, the electrode fingers 24d of the opposing electrode 24D also have a sawtooth pattern. By using the interdigital electrode  
15 of FIG.9B, the electro-optic characteristics are also averaged similarly to the example of FIG.9A and the viewing angle characteristic of the IPS liquid crystal display device is improved.

FIGS.10A and 10B are diagrams showing the  
20 viewing-angle characteristics of the IPS liquid crystal display device of 15-inch size having a resolution of 1024 x 765, wherein FIG.10A corresponds to the case in which the interdigital electrode of FIG.7B is used, while FIG.10B corresponds to the case  
25 in which the interdigital electrode of FIG.8A is used. In FIGS.10A and 10B, the contours represent the contrast ratio CR.

Referring to FIG.10A, it can be seen that the liquid crystal display device has an excellent  
30 viewing angle characteristic, while it is still noted that there is an inversion of contrast occurring in the azimuth angle of 45°.

In the case of FIG.10B, on the other hand, it can be seen that the contrast inversion occurring  
35 in the azimuth angle of 45° is vanished.

It should be noted that there are other various ways to form plurality of regions of different

1 electro-optic characteristics in the pixel region.  
For example, FIG.11 shows the case in which the  
thickness of the liquid crystal layer 13 is changed  
within a pixel, wherein it should be noted that FIG.11  
5 represents the cross-section crossing the pixel  
electrode 24B or the opposing electrode 24D in the  
direction of the source bus line. In FIG.11, those  
parts corresponding to the parts described previously  
are designated by the same reference numerals and  
10 further description thereof will be omitted.

FIG.12 shows an example in which the  
direction of the liquid crystal molecules in the non-  
activated state of the liquid crystal display device  
is changed within a pixel. It should be noted that  
15 FIG.12 represents the cross-section crossing the pixel  
electrode 24B or the opposing electrode 24D in the  
direction of the source bus line. In FIG.12, too,  
those parts corresponding to the parts described  
previously are designated by the same reference  
20 numerals and further description thereof will be  
omitted.

Further, FIG.13 shows another example of  
achieving the effect of the present embodiment by  
changing the tilting direction of the liquid crystal  
25 molecules within a pixel. It should be noted that  
FIG.13 represents the cross-section crossing the pixel  
electrode 24B or the opposing electrode 24D in the  
direction of the source bus line. In FIG.13, too,  
those parts corresponding to the parts described  
30 previously are designated by the same reference  
numerals and further description thereof will be  
omitted.

Further, the present invention is not  
limited to the embodiments described heretofore, but  
35 various variations and modifications may be made  
without departing from the scope of the present  
invention.